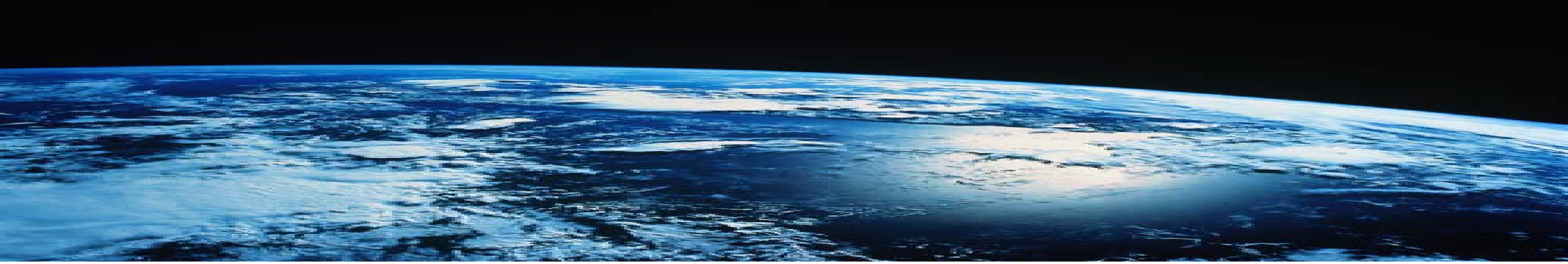

Tropical Climate Variability During the Satellite Era: What Can We Infer About Climate Sensitivity?

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- Two types of short-term climate variability are accessible within the satellite record– tropical intraseasonal variability (20-90 days) and ENSO (3-5 years).

- Brief look at each type event in terms of how near-global variations in top-of-atmosphere net radiative flux relates to surface temperature.

- *How do the radiative fluxes that affect heat balance of the planet on these two time scales relate to those expected in the face of external radiative forcing?*

A zero-dimensional, linear framework:

External radiative forcing (~ constant)

No change on our time scales of interest

$$C_p \partial T_s/\partial t = \overbrace{-\lambda T_s \quad + \quad N}^{TOA_{net}\text{ flux measured by satellite}} \quad + \quad \cancel{f} \quad + \quad S$$

Ocean mixed layer heat content tendency

Linear feedback (Planck effect + wv, clouds, lapse rate...)

$$\partial TOA_{net}/\partial T_s = \lambda$$

Stochastic internal radiative forcing

Non-radiative forcing (e.g. mixed layer heat exch w/ deeper ocean)

Equilibrium climate sensitivity $\equiv \delta T_s = f / \lambda$

Case A: Intraseasonal (20-90) convective variability over the tropical western Pacific Warm Pool (MJO just one manifestation)

Bantzer and Wallace, 1996: Precipitation links to global temperature signals

Lin and Mapes, 2004: Lifecycle composites of TOA fluxes over W. Pacific

Spencer et al., 2007: Tropically-integrated TOA / T_{air} signals

Robertson et al., 2012 (In revision, *J Climate*) MERRA, Obs comparisons

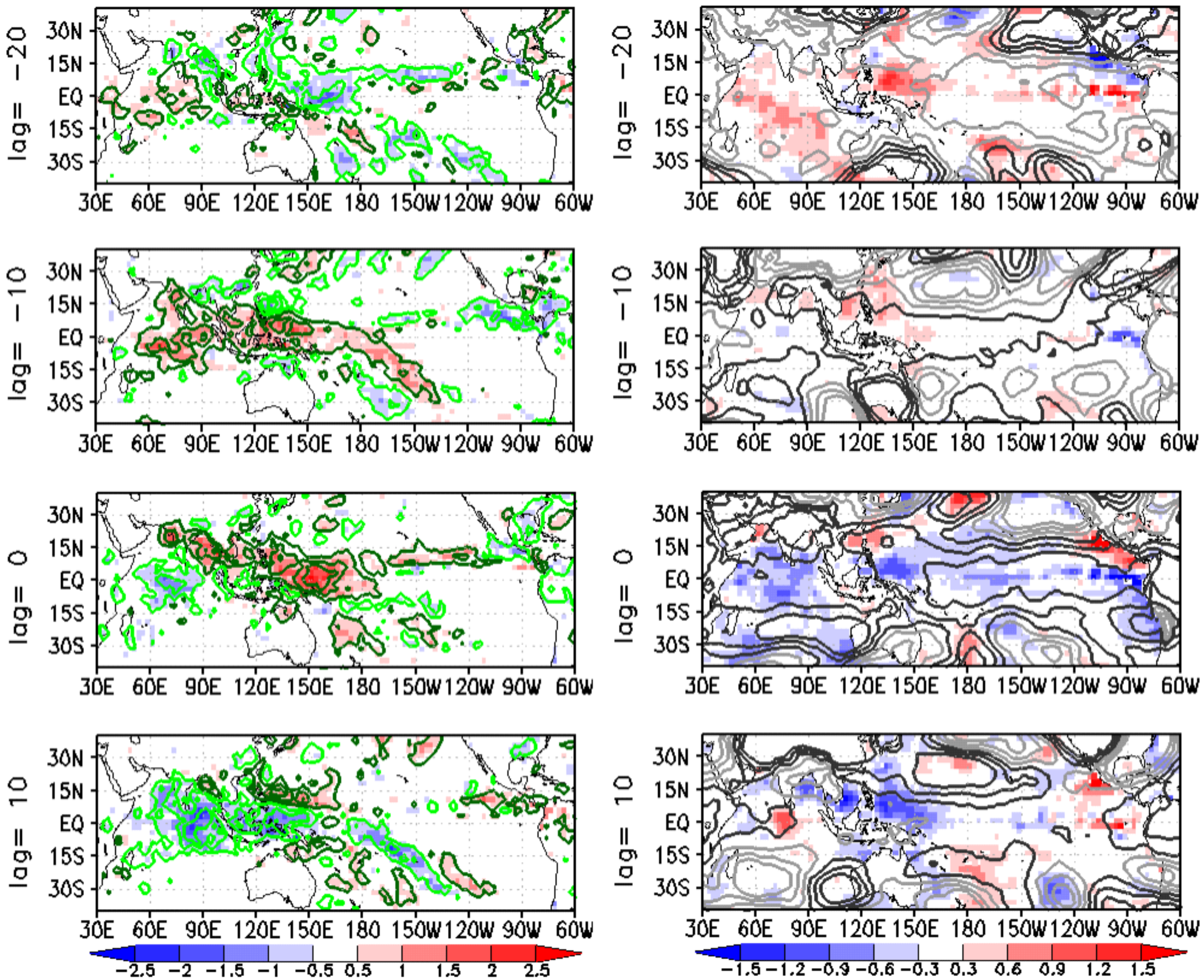
Approach:

- Composites of ISV anomalies (departure from daily resolved annual cycles) using daily data from a variety of satellite, reanalysis sources (TRMM, GEWEX SRB, MERRA reanalysis, OAFlux…)
- Reference phase of event to max tropical tropospheric temperature averaged over the tropics

Evolution of Composite Intraseasonal Precip, SST, T_{tropo}

TRMM precip (shaded)
MERRA reanalysis (contoured)

Reynolds SST (shaded)
MERRA T-trop (contoured)



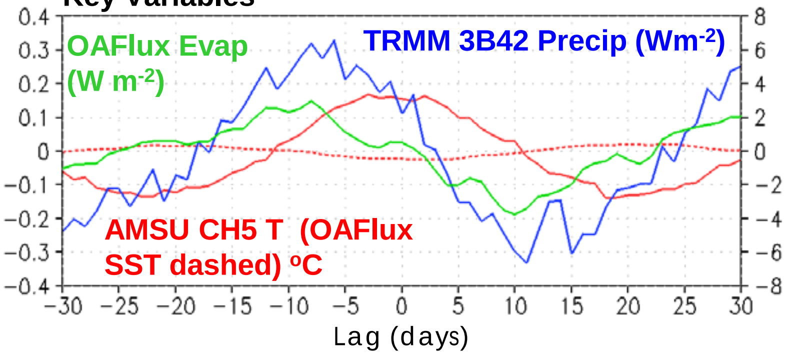
Positive (negative) contours

Positive (negative) contours

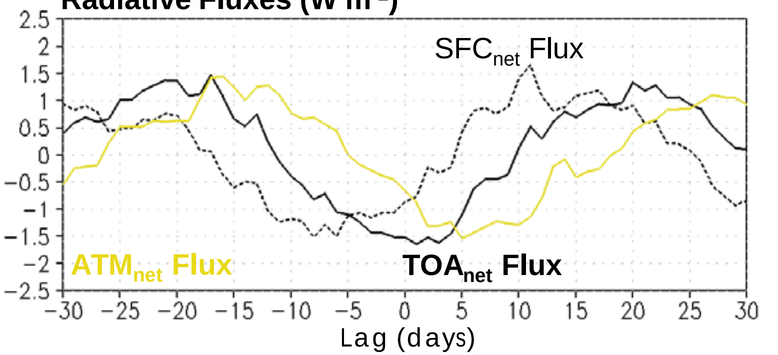
- As precipitation increases over the Warm Pool, mean tropospheric T increases but SST decreases.
- Thus, systematic ocean-atmosphere energy exchange is evident.

Composite Intraseasonal Flux Anomalies Averaged Over the Tropical Oceans (20º N/S)

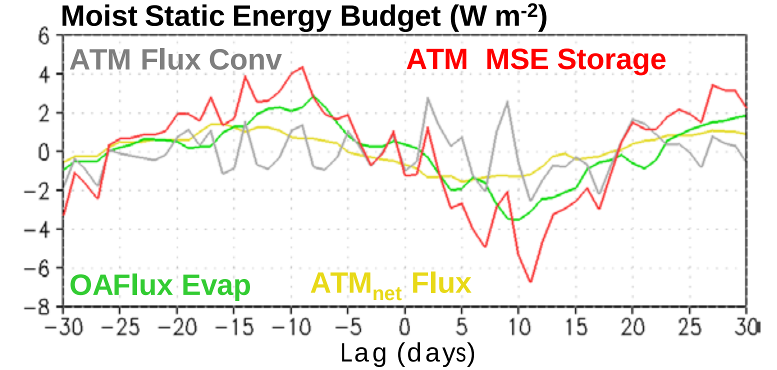
Key Variables



Radiative Fluxes (W m-2)



Moist Static Energy Budget (W m-2)



- Evaporation and precipitation lead max in T-troposphere ~ 8 days with TOA loss slightly lagging in time. Evaporation is insufficient to support precipitation → boundary moisture transport → strong dynamical coupling.

- **TOA_{net}** energy loss follows max T-trop. SFC_{net} leads because of LW emission.

- Storage of heat in atmosphere almost balanced by Evaporation + ATM_{net}. Weak net lateral transport of moist static energy (c_pT + gz + Lq).

- Net input of energy from ocean to the atmosphere results in lagged rejection of energy to space (**TOA_{net}**). *Significance of this energy exchange?*

In the Context of Our Simple Model…

Clearly the intraseasonal LHF and small (but noisy) implied energy transport are much larger than *random* atmospheric radiative forcing, so we can ignore N.

$$C_p \partial T_s / \partial t = -\lambda T_s + S$$

Here the non-radiative forcing, S, is composed of LHF plus boundary MSE flux. But they (through wind speed) are part of the dynamical response to convection, and convection is responding to pre-conditioning by temperature and moisture.

So, the TOA_{net} flux relationship to T is not a response to an *external* forcing agent. The problem clearly differs in nature from that of $\Delta CO2$ forcing where the radiative forcing is essentially independent of the adjustment.

We conclude that λ is not representative of a climate feedback, but rather, radiative convective adjustment of the current climate.

Case B: ENSO Warm and cold SST events (2-5 year scale)

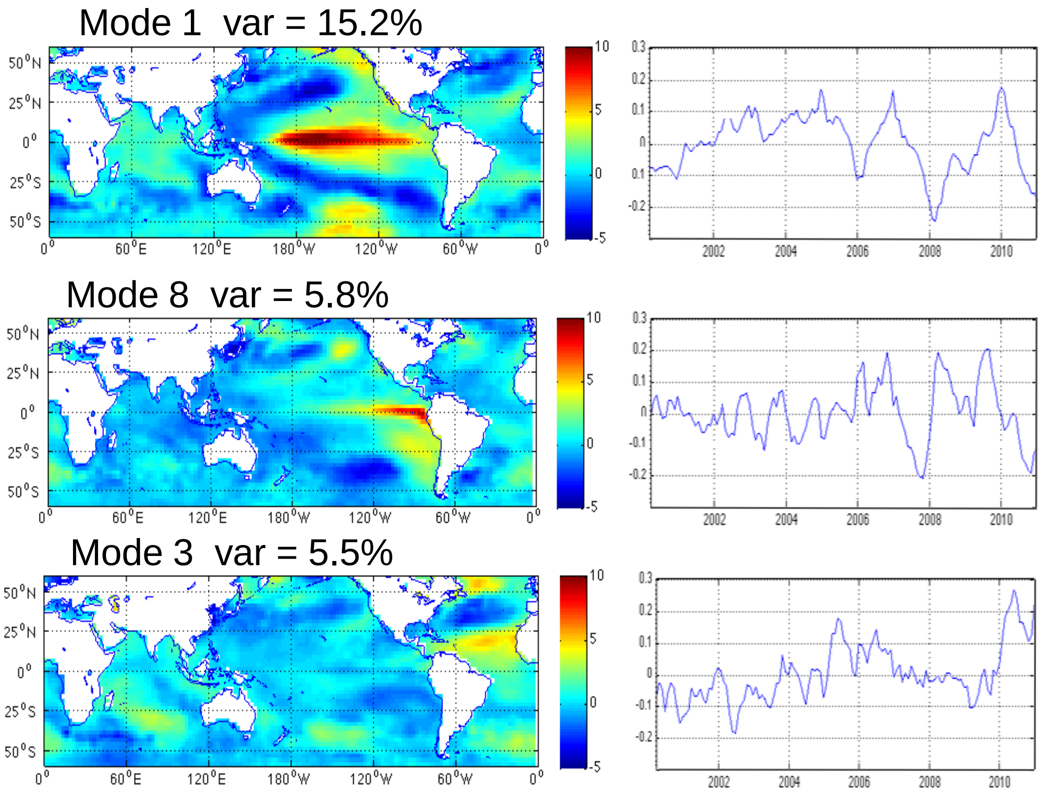
Chou, 1994: Tropical Pacific TOA fluxes
Soden, 1997: Variations in the tropical greenhouse effect
Cess et al., 1999: Cloud forcing changes during 1997-8 El Nino
Zhang and Sun, 2006: NCAR model clouds and water vapor
Dessler, 2010; 2011: Water vapor and cloud feedbacks
Spencer and Braswell, 2011: Recent TOA fluxes and climate sensitivity

<u>Rationale:</u> Lifetime of SST variations >> atmospheric adjustment time (~ months)
so we assume the sense of forcing / feedback is better clarified

<u>Approach:</u>

- High precision CERES on Terra since Mar 2000 provide TOA_{net} anomalies relative to annual cycle
- Principal Component Analysis of SST to define modes of variability
- How do they relate? How well do flux variations relate to short-term ocean heat content changes (Levitus: 2005,2009)?

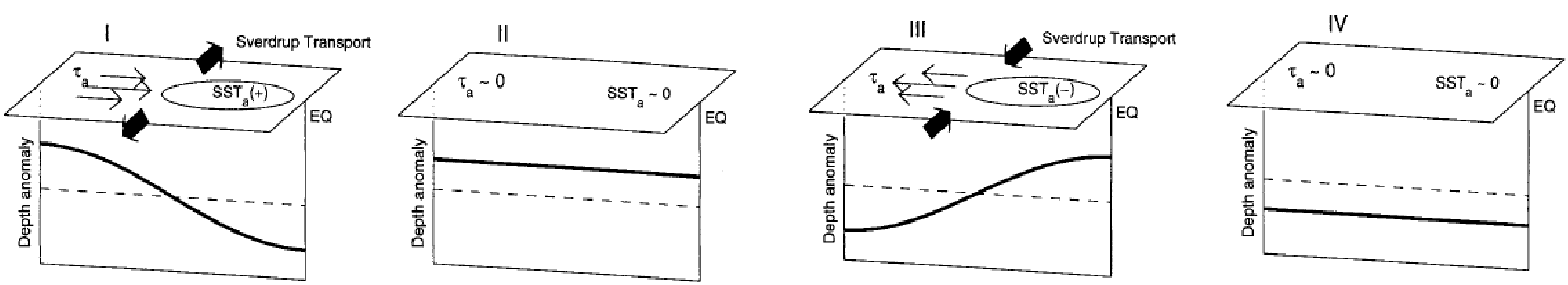
SST EOFs and PCs 2000-2010 *(Rotated)*



First two modes are consistent with Meinen & McPhaden (2000) "discharge-recharge" and "east-west tilting" modes.

Third mode has both North Atlantic Oscillation and ENSO components.

Four Phases of Recharge Oscillator *(Jin, 1997; Meinen and McPhaden, 2000)*



Mature El Nino

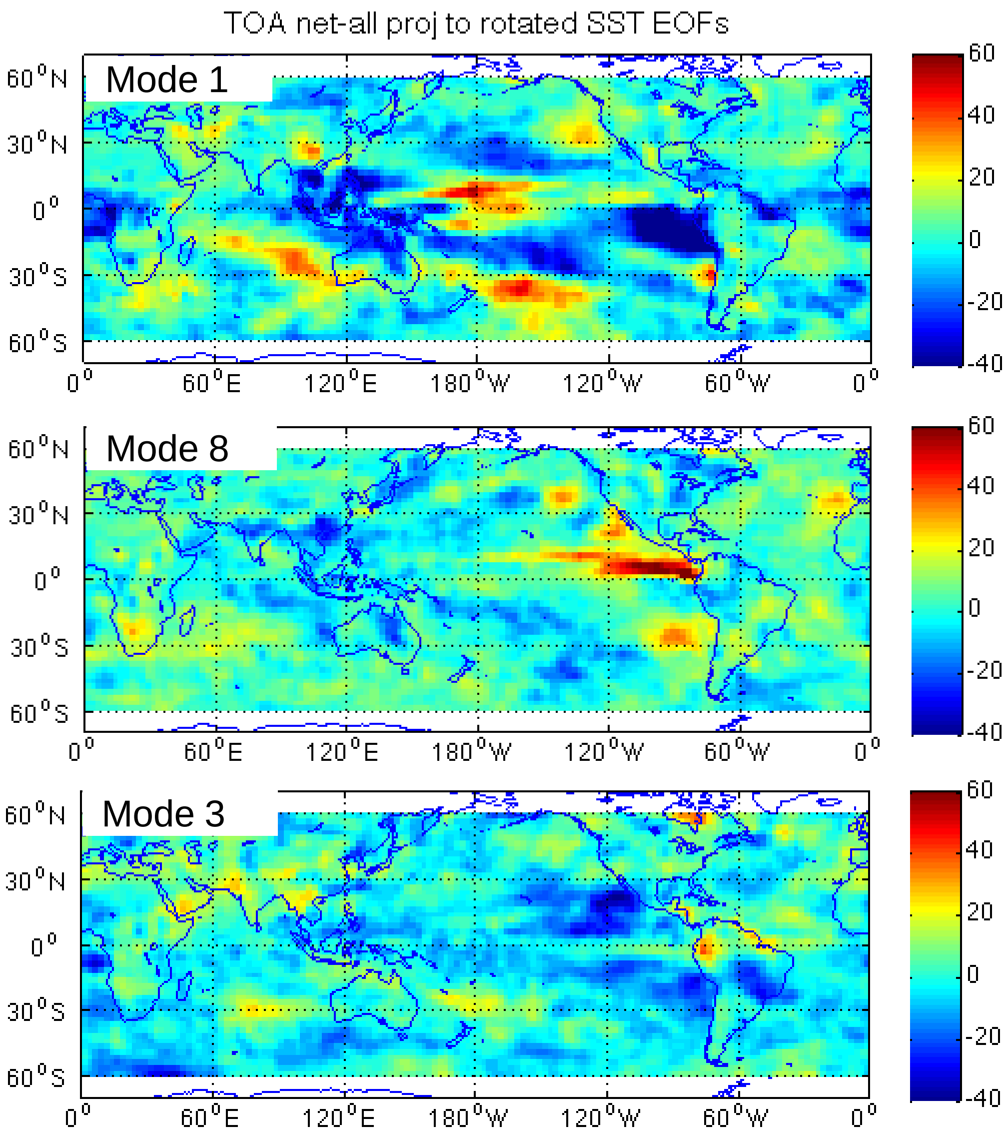
Transition

Mature La Nina

Transition

Projection of TOA net flux on PCs of SST Modes

Net radiative effects associated with important higher order SST modes are focused in the eastern tropical Pacific



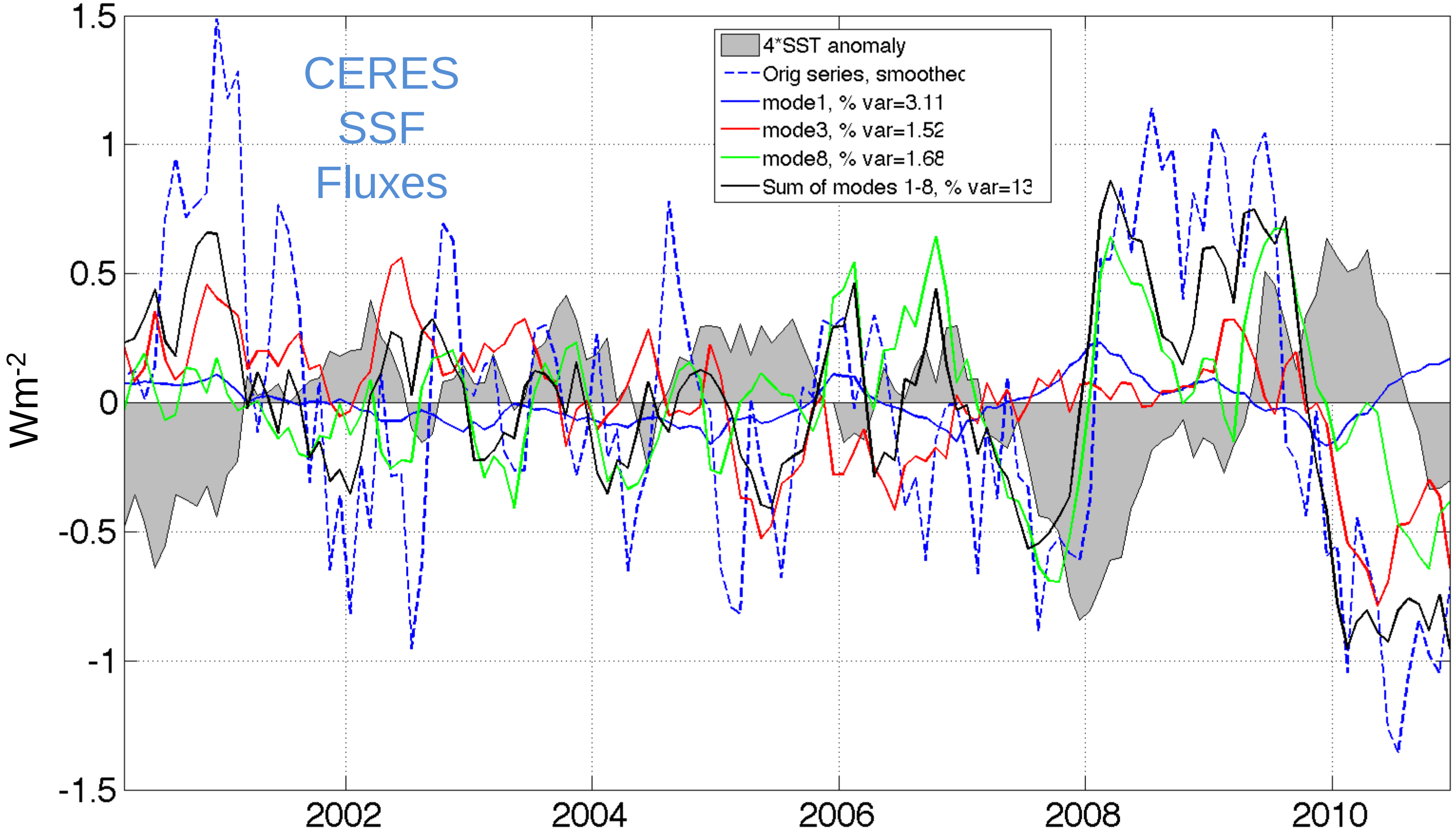
Mode 1: Enhanced deep cold clouds in central Pacific increase TOA_{net}. Surrounding region of compensating regions of TOA net radiative loss

Mode 8: Strong TOA cloud effects in E. Pacific ITCZ and subtropics due to upwelling controls on static stability (Deser et al, 1993)

Mode 3: Enhanced TOA effects in east Pacific ITCZ and subtropics. Inversion strength changes

TOA_{net} Projected Onto PCs of SST Anomalies

All quantities are area-averaged over 60º N/S domain

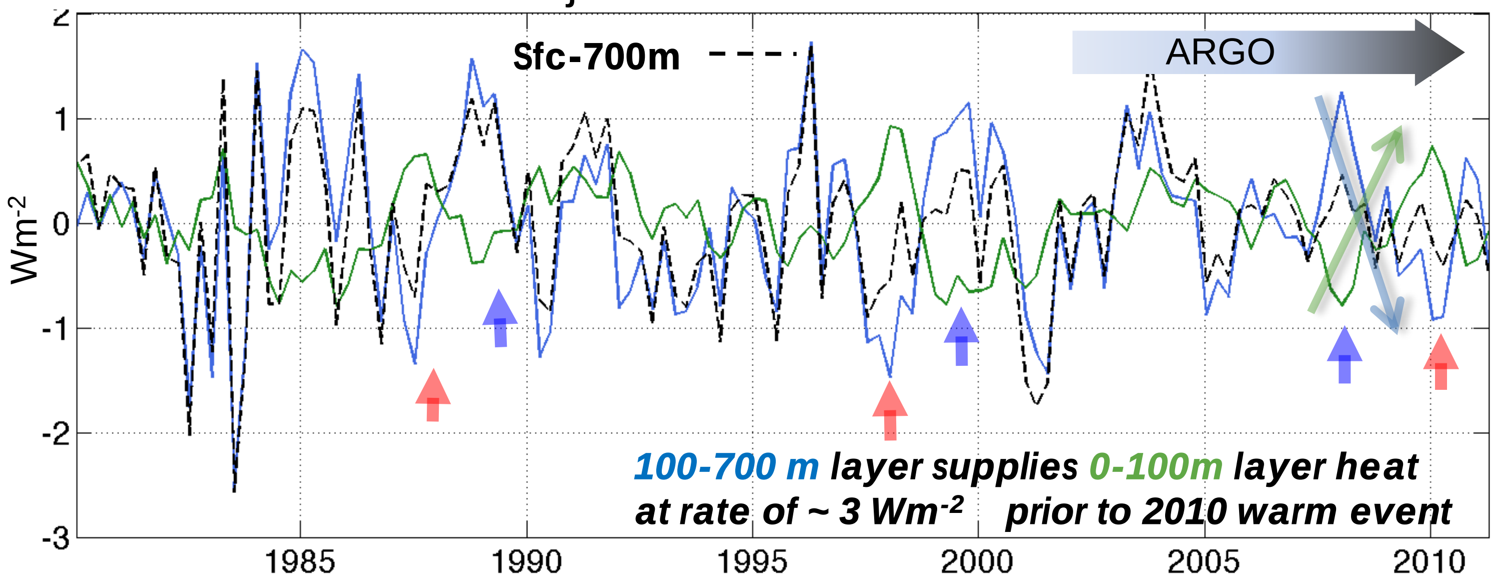


Equatorial E. Pacific SST gradient and Atlantic ENSO/PNA modes dominate

ENSO-related Global Ocean Heat Content Change

Levitus et al (2009; http://www.nodc.noaa) *(Decadal frequencies removed)*

Heat exchange between Sfc-100m vs 100-700m layers shows thermocline adjustments & heat redistribution



- Global ocean heat content changes in sfc-100m layer are anti-correlated with those from 100-700m; however, great observational uncertainties are present in net 0-700m changes in historical record.
- Roemmish and Gilson (2011) show that using only corrected Argo float data, net heat variations are 3-5x smaller than for either layer → *upper ocean restratification dominates TOA flux forcing.*

Synthesis and Implications

- TOA radiative effects associated with East-west gradient of SST in the E. Equatorial Pacific are particularly important in determining TOA_{net} ***on a global basis.*** This response is part of the coupling of ocean upwelling and equatorial thermocline tilting to atmospheric stability and cloudiness.

- Substantial evidence that restratification of upper-ocean heat content associated with the "recharge oscillator" mechanism dominates SST forcing with TOA_{net} (via surface fluxes) playing a much smaller role.

- While TOA fluxes are evidence of energy being stored / released from upper ocean, these events are *slaved* to coupled dynamics / kinematics of the oscillator.

$$C_p \partial T_s / \partial t = -\lambda T_s + N + f + S$$

Synthesis and Implications cont.

- With much larger separation in ocean, atmosphere time scales forcing / response is much clearer than for ISV.

- However, ultimately, the “forcing”, S, is still internal to the climate system (winds couple “oscillator” and atmospheric heating) so that regional dynamics can be different than that expected for anthropogenic forcing.

- Coupled model ENSO shortcomings have also shown little correlation with variations in model climate sensitvity (Zhu et al., 2007; Sun et al., 2009). Nonetheless, ENSO-related climate variability is a crucial “laboratory” for process understanding and model physics improvement.

BACKUPS

Wind & static stability anomalies are correlated to SST modes